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THE EFFECT OF COMMERCIAL FERTILIZERS ON ALFALFA
(MEDICAGO SATIVA L.) SEED PRODUCTION ON THE GRAY
WOODED SOILS OF ALBERTA

Frank Henry White
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University of Alberta

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my many friends and acquaintances in London
and the country, and the many who have
been kind enough to write to me.

Yours very truly,
John Lubbock

I have just received from the
British Museum the following
list of the names of the
persons who have been
appointed to the various
departments of the
Museum.

Respectfully,
John Lubbock



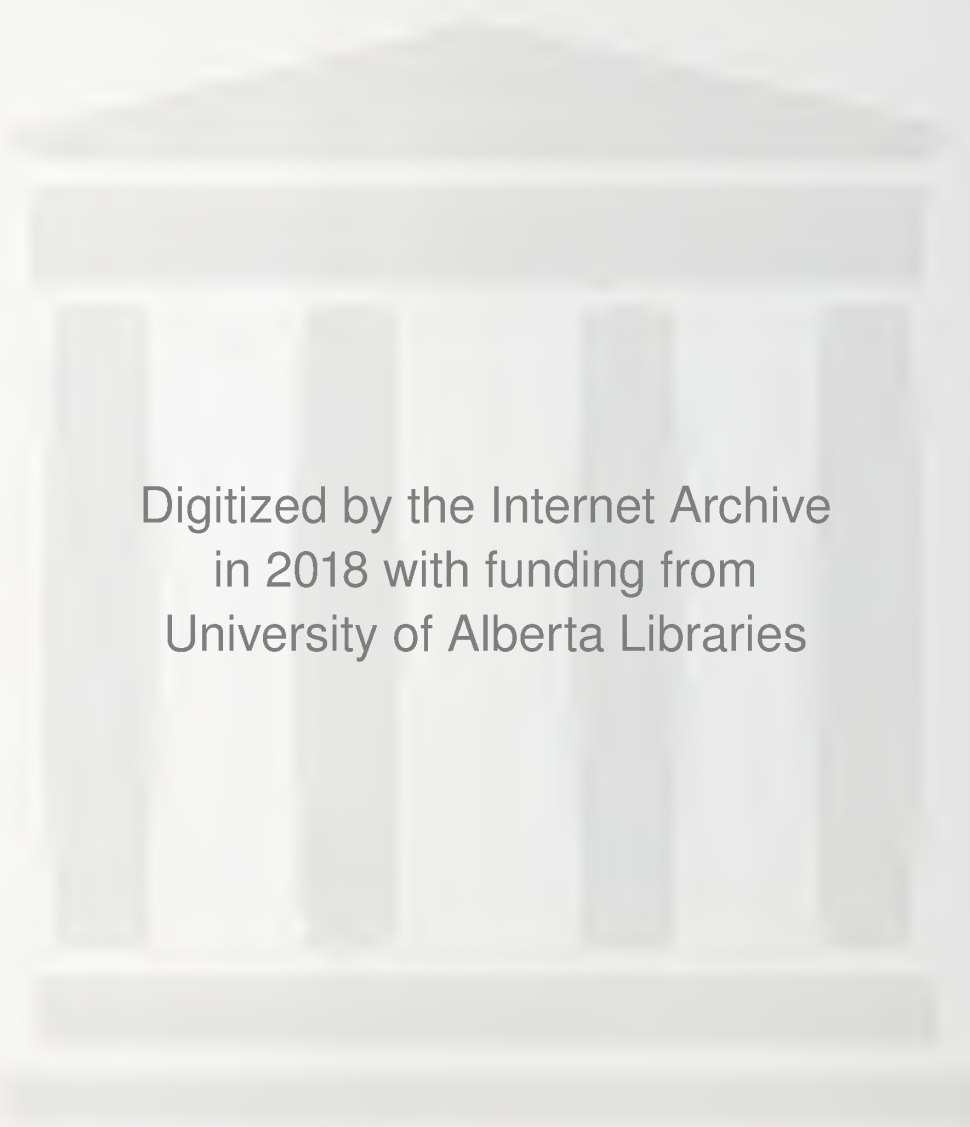
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INTRODUCTION

During the past half century numerous research workers have studied the causes of variability in seed production in alfalfa. In so doing climatic and various other factors affecting seed setting have been most intensively considered. This paper is a report on experiments designed to study the comparative effects of certain commercial fertilizers and nutrient water culture solutions on seed production in alfalfa.

This problem has considerable importance from both theoretical and practical standpoints. It has usually been evident wherever alfalfa has been grown that the seed crop has differed widely in yield from year to year. Extensive research into the cause of this phenomenon has not yet given conclusive results. The effects of self- and cross-pollination, temperature relationships during flowering and seed formation, moisture

supply during anthesis, as well as the effect of various insects on flower tripping have been studied. Most of these factors have been found to have some bearing on the reproductive processes of the plant. In the laboratory, under controlled conditions, environmental factors such as heat, light, and moisture supply have been studied concerning their effect upon variability in pollen fertility and rate of pollen tube elongation.

At the present time, if some element or group of elements could be determined which directly influenced the reproductive fertility of the plant as measured by seed yield, one would be much more able to elucidate the complex problem of the variability in seed production of alfalfa. It is quite probable that nutrients, other than those studied in these experiments, such as the various auxins, hormones, and vitamins present in the plant, may have considerable effect on the reproductive processes in alfalfa. Various minor elements, for example boron, manganese, magnesium, iron, and copper and others may exert some fundamental influence upon these processes. It was in the hope of determining whether nutrition had any such effect on seed setting in alfalfa that these experiments were undertaken.

The practical aspect of this problem is of greatest importance at this time, particularly in respect to the gray wooded soils of Alberta. Alfalfa is one of

the most valuable crops used for forage purposes in practically all the great agricultural parts of the world. In Alberta during the past decade, it has become widely distributed in central and northern localities where it is used for fodder and green manure crops. However, owing to its great variability and uncertainty in fertility, it is not maintaining its seed yield. If, by the use of commercial fertilizers, seed production could be increased or rendered more dependable, this economically important problem would be much reduced.

PART I

FIELD EXPERIMENTATION

It has become very evident from reading the literature dealing with this subject that few studies have been made concerning the effect of fertilizers on alfalfa seed production. Thus one may conclude that it is a relatively new method of approach to the problem of seed production in this crop. As a result of this it was found necessary to investigate literature concerning other crops in order to determine the elements or group of elements likely to have the greatest effect generally upon seed production. Many annual and a few perennial crops have been studied in connection with fertilizer effects upon seed yields. These studies, although not directly related to seed production in alfalfa, might reasonably be expected to suggest fertilizers which might be effective in connection with the problem in hand. Many field experiments have been conducted using nitrogenous fertilizers in different forms and rates of application, which show that seed crops react differently, depending upon the crop studied.

LITERATURE REVIEW

Miles (36) in Indiana conducted fertilizer experiments with corn, studying the effect on seed and fodder yields. Under his conditions nitrogen had no effect upon growth as compared with phosphorus and potassium. The application of phosphorus alone increased height 9 to 10 inches and, with further addition of potassium, height was increased by 12 inches. Nitrogen had no effect on maturity and early development, whereas phosphorus and potassium caused earlier tasseling and hastened maturity. No increase in seed yield was obtained from fertilizer applications under the conditions of the experiment.

Reynolds and Rea (41) in Texas applied fertilizers to cotton and found increase in lint production owing to nitrogen applications. Phosphatic fertilizers gave no significant increases in cotton yield when applied alone. Increases of cotton of 14 to 18 percent resulted from the application of 4-8-4 complete fertilizer. All increases were, however, considered unprofitable. Davis and Jones (7) in California obtained consistent increases in yield of rice from the applications of 100 to 200 pounds per acre of ammonium sulphate.

RESULTS

1. Effect of temperature on the rate of reaction

The reaction was carried out at various temperatures and the rate of reaction was determined by measuring the volume of gas evolved. The results are shown in Table I. It is seen that the rate of reaction increases with increasing temperature. This is to be expected since the rate of reaction is a function of the activation energy of the reaction. The higher the temperature, the more molecules have sufficient energy to overcome the activation energy barrier and the faster the reaction proceeds.

2. Effect of concentration on the rate of reaction

The reaction was carried out at various concentrations of the reactants and the rate of reaction was determined by measuring the volume of gas evolved. The results are shown in Table II. It is seen that the rate of reaction increases with increasing concentration of the reactants. This is to be expected since the rate of reaction is a function of the concentration of the reactants. The higher the concentration, the more molecules are present and the faster the reaction proceeds.

A study of the time of application showed fertilizing at planting time to be much more effective than applications at tillering and flowering stages of development. Hunter (26) at Cambridge also studied the time factor in fertilizer applications. Sodium nitrate was added at five growth stages of barley. Fertilizer applications were found to be most effective when applied at sowing or when first tillers appeared above ground. Early applications increased the number of tillers per plant but not the number of seeds per head. Later applications increased nitrogen content of seed but not the yield. Watson (52) in Rothamstead obtained similar results with NaNO_3 fertilizer applied to wheat. The earlier the application, the greater was the increase in seed yield, the increase corresponding to the increase in number of tillers.

Pultz (40) at Washington determined the effect of ammonium sulphate on the yield of sugar beet seeds. He wished to maintain the quality of the seed and, at the same time, the quantity. Applications of 750 lb. per acre in the fall, in the spring, half in the fall and half in the spring, gave increases in seed yield of 840, 1000, and 920 pounds respectively above that of the untreated plots, an increase of 285 pounds being statistically significant. The fertilized plots were much more vigorous, with longer seed branches and a larger number of

flowers per flower stock. Warner (51) found that applications of ammonium fertilizer during the blooming stage increased the rate of fruiting of cotton, prolonged the season of bloom production, and thus obtained maximum chances of higher yields. The results of these various experiments indicate that nitrogenous fertilizers might be expected to produce considerable effect on seed production and vegetative growth when applied to annual and biennial crops. Similar effects might be expected on the yields of perennial crops. Evans (16) found this to be true. Nitrate of soda applied at the rate of 0 to 320 pounds per acre had significant effects on timothy seed production. Increasing the rate of fertilizer applications increased the seed yield proportionately up to a maximum, following the economic law of diminishing returns. Vegetative yields showed a small tendency to increase with the increase in seed production owing to the fertilizer application. He concluded, therefore, that timothy did not make a vigorous vegetative growth at the expense of seed production under the conditions of his experiments. North and Odland (37) found the seed yield of Rhode Island Colonial Bent grass increased in proportion to the amount of nitrogen fertilizer applied to the soil. Heavy applications, however, caused severe lodging and consequent loss of seed.

The application of phosphatic fertilizers has also been found to have a highly beneficial effect on seed production in several crop plants. Fellers (17) studied phosphate fertilizer effect on soybean seed production. He found that 500-pound applications were detrimental to seed production, whereas 100-pound applications increased the yield in the proportion of 2.16 to 1.8 compared with the untreated plots. Boswell and Jodidi (6) concluded from their experiments with peas that phosphate fertilizer applications had no significant effect upon seed yield or quality. The time of maturity was somewhat shortened. Warner (51), Reynolds and Rea (41) both found that phosphate applications to cotton increased the seed yield significantly through the increase in numbers of blooms produced and the number of seed bolls formed. Truog and Hamburg (49) concluded that 200 pounds of 0-20-10 was most effective in increasing seed yield of peas but with further increase in the potassium content of the fertilizer the yield was decreased. Corn yield also was increased by applications of phosphate. Greene (21) substantiated the claim that phosphate increased seed yields in field experiments with peas, oats, wheat, and barley. Applications of 125 pounds of triple superphosphate gave significant increases for all crops studied. Toevs and Orien Baker (46) reported that a 300-pound application of triple superphosphate applied to red

clover increased the seed yield to 300% of that of untreated plots. Such results suggest that phosphate fertilizers are very likely to enhance seed production of most crops.

The use of potassium fertilizers alone does not, as a general rule, have an effect on seed yield; in combination with other elements, however, far reaching effects may be obtained. Schuster (42) found this to be true with soybeans. Seventy-five pounds of muriate of potash fertilizer increased soybean yield by four bushels per acre over a six-year period. In combination, 100 pounds of sodium nitrate and 250 pounds of acid phosphate increased yield by ten bushels per acre. This result, Schuster concluded to be due to the earlier maturity of the potassium fertilized plots. Well developed, ripe seeds were harvested, whereas in all other plots the seed was green and shrunken at harvest time. Hartman and Powers (22) concluded from pot culture tests that small potassium fertilizer applications increased wheat yield significantly. Avdonin (2) studied the effect of potassium on millet, and showed that fertilizers containing this element were most effective when applied during the vegetative growth of the plant. Frequent applications during this period increased the seed yield three-fold and the forage yield two-fold. Applications late in the growing season had a deleterious effect. Kurockin (29) showed that clover plants were greatly benefited by the addition of phosphate and potassium fertilizers during the flowering period. Applications at bud

formation gave seed increases of 29 to 38 percent. Vsov (50) conducted fertilizer tests with lupins and found nitrogen, phosphate plus potassium, and potassium alone had no effect on the length of vegetative growth nor on the seed yield. The quality, germination, rapidity of emergence, and 1000-grain weight, however, were materially improved.

Dijakova (10) studied the effect of fertilizers on alfalfa, concluding that phosphates applied at seeding time gave the largest seed yield. Applications were made at the rate of 120 kilograms per hectare of phosphate and 30 kilograms per hectare of nitrate. Wyatt and Newton (54) concluded from experiments with several fertilizers that potassium sulphate applied with 16-20 ammonium phosphate gave the largest increase in seed yield of cereal crops. At the same time, fertilizer experiments with legumes gave similar results in hay yield increases. Glynne (19) applied high sulphur fertilizers to wheat and found significant increases in yields of seed. The beneficial action of the sulphur was due to the liberation of nitrogen from the organic matter of the soil. Nitrogen was the limiting element in crop production on the soil Glynne used. Kaluzhaskii (27), working with millet, increased the seed yield 5.5 times by the addition of large amounts of sulphur. He concluded that sulphur added to the soil increased the availability of the phosphoric acid, which was present in the soil in the form of rock phosphate. Tolman and Stoker (48) reported that applications of sulphur and nitrogen fertilizers materially

increased the seed yield of sugar beets on Oregon soils.

Calcium carbonate in the form of lime, chalk, marl, and limestone has been used in many fertilizer experiments to increase seed and vegetative yields of crop plants. Its use has, however, been to correct the soil acidity in most cases and not to nourish the plant. Hughes (25) indicated that large applications of lime had little detrimental effect and slightly increased the yield of wheat. Konovalon (28) studied lime nutrition in relation to magnesium and found that by increasing the lime content, the magnesium remaining the same, the yield of millet and oats increased until the ratio of lime to magnesium became 6.7 to 1.0.

The use of fertilizers containing minor elements such as boron, iron, and magnesium have been studied in relation to seed production. McHargue (33) found that he could materially increase the yield of oats by the addition of boron to limed peat soils. A similar result was obtained with flax. Bobka and Matveeva (3) showed that harmful effects from overliming could be removed by the application of boron in small quantities which resulted in increased seed production. McMurty (35) studied the effect of borax fertilizer on tobacco seed production, and found that small applications prevented terminal buds from dying back and so greatly increased seed production. Shkolnick (44) tested soybean reaction to borax fertilizer and concluded that large increases of seed and hay could be obtained through small applications. He noted similar results for peas, hemp, and sunflowers.

Tokuoko and Hitoshi (47) applied borax fertilizer to rice plots and obtained increased seed yields even though the amounts applied were only between 0.02 and 2 parts per million.

Dmitriev (11, 12, 13) reported that molybdenum and boron added to calcium, phosphorus, and potassium fertilizers had a positive, beneficial effect on red clover seed yields.

Boron fertilizers, he concluded, hastened blooming, stimulated fruiting, and increased seed setting when applied in the spring, but was less effective when applied at the budding stage of growth. Dijakova (9) experimented with borax fertilizers in relation to alfalfa production. He found that borax fertilizers speeded up growth and development and increased seed yield whether the fertilizer was applied before or after sowing the crop. Piland and Ireland (38) also conducted field experiments with alfalfa and borax fertilizer. Where borax was applied at the rate of 20 pounds per acre seed production was good, whereas plots with no treatment were considered a failure, only scattered pods being developed.

The element manganese has been used in very limited amounts as a fertilizer for some crop plants with some benefit to seed production. Aso (1) found that rice yields were substantially increased by applications of manganese chloride. Other workers have substantiated this using other manganese

compounds. Demkina (8) applied manganese sulphate to flax seed and obtained a marked stimulatory effect on growth; seed production was increased to the extent of 35% in pot tests. Hiltner and Korff (23) found manganese sulphate fertilizer to be highly beneficial to oats grown on various soil types to which a basic fertilizer--guano--had previously been added. In each case the size of plant and yield of seed was increased when manganese sulphate was added. These results thus seem to indicate that applications of various fertilizers may be beneficial for increasing seed production of many of our field crops.

MATERIALS AND METHODS

When the experiment here reported was started in the spring of 1940 two fields were selected having the typical gray soil profile. Each field was beginning its second year of growth; both were apparently uniform stands of registered Grimm alfalfa. Unfortunately at the end of the season one had to be discarded because of the presence of Altaswede and alsike clover and, consequently, no yield data were obtained from this field. The remaining field was designated as Field A for reference purposes. In 1941 another similar field designated as Field B was selected for study. Thus two years' data are available for Field A and one year's

data for Field B.

Field A was divided into four sections, each 120 feet by 63 feet designated as one replicate. The replicate was subdivided into 18 plots: three banks of six plots each with a twenty-foot alleyway between banks. Plots were 10.5 feet wide and 20 feet long. The wide alleyway between banks of plots provided turning space for the tractor and drill without damage to the vegetation on the plots. The machine later was found to be too inefficient and its use was abandoned.

Field B, selected in 1941, was set up somewhat differently. Three banks of six plots each constituted a replicate. The size of plot was 10.5 feet by 22 feet, that is, two feet longer than plots in Field A. This allowed for the elimination of border effect without the use of wide alleyways. The fertilizers were spread by hand. The four replicates thus covered an area of 132 feet by 126 feet.

As suggested by the numerous fertilizer experiments which have been conducted in connection with seed production, the following four fertilizers were selected, each with its approximate percentage composition as follows:

Fertilizer	Nitrogen N%	Phosphorus P ₂ O ₅ %	Potassium K%	Sulphur S%	Gypsum %
Ammonium Phosphate (16-20)	16	20	-	14	--
Ammonium Phosphate (11-48)	11	48	-	2	--
Single Superphosphate (2-19)	2	19	-	9	50
Complete (9-27-9)	9	27	9	10	--

Fertilizer applications were made at two rates for each kind, namely, 25 pounds per acre and 75 pounds per acre. Both rates were deemed practical from the standpoint of the farmer and were sufficiently different to expect some differences in yield.

The fertilizers were applied as early in the spring as possible and at two time intervals. Half of the treated plots were fertilized each year; the other half were treated every other year. All plots except the checks were fertilized in 1940 in Field A but in 1941 only half were treated. In Field B all plots except the checks were fertilized in 1941 and half will be fertilized in 1942. Two untreated check plots were thus left in each replicate, making a total of eighteen plots per replicate. The resulting plan contained 72 plots, eight untreated and 64 treated, the latter consisting of four plots treated annually at the 25-pound rate, four treated annually at the 75-pound rate,

four treated biennially at the 25-pound rate, and four treated biennially at the 75-pound rate for each of the four fertilizers.

The fertilizers were applied by hand because of the damage done to the vegetative growth by the drill and tractor wheels. Each fertilizer was weighed out for each plot separately and placed in a tin can with a perforated bottom. The can was hand-shaken over the entire plot so that an even application of fertilizer was obtained. This proved quite satisfactory if there was not too much wind movement.

Harvesting was done when 50 to 75 percent of the seed pods had turned black. The samples were measured by the use of a half-inch round steel bar bent to a circle, with a uniform diameter, and bent so that the free ends of the circle overlapped considerably. The bar was then adjusted to the shape of a coil of a corkscrew. This enabled the circle to be twirled horizontally into the matted growth so that only plants within the enclosed area would be included in the sample. All vegetation within the steel circle was cut close to the ground with a sickle. Four samples were taken from each plot and bulked, giving a total sampled area of $4\pi r^2$, r being the radius of the circular sampler, viz., 16.5 inches. The green composite sample was weighed, wrapped in a fine cotton wrapper to avoid loss of seed, tagged with

the plot number, and placed to dry.

Dry weight of vegetative growth was also taken from a representative number of plots. The sample from each plot was threshed separately by means of a small rod-row threshing machine. The seed was later cleaned through a small Clipper Cleaner which removed most of the small weed seeds and other foreign matter. Owing to the presence of a few Altaswede and alsike clover plants in the samples, hand picking of the seed sample was found to be necessary. The final sample of cleaned seed was weighed in grams, and this weight was then converted to yield in pounds per acre.

Because of various uncontrollable environmental factors, seed yields were very low and, under usual farm conditions, the crop would have been cut for forage purposes. The green weight data were taken in 1941 only, and were found to be quite adequate for analysis. The yields of both fodder and seed are reported in grams per sample or plot, which can be converted to yield in pounds per acre by multiplying the number of grams per sample by the conversion factor 4.041.

All data were treated statistically for the determination of the significance of differences in results from the various treatments. The analysis of variance was conducted for the data obtained on seed yields in both years separately and in the two years combined, and on forage yields for 1941 only. The analysis of covariance on

the first instance, and found it to be.

The object of the present investigation is to determine the effect of the various factors which influence the rate of the reaction. The first of these factors is the concentration of the reactants. It is found that the rate of the reaction increases with the concentration of the reactants. The second factor is the temperature. It is found that the rate of the reaction increases with the temperature. The third factor is the presence of a catalyst. It is found that the rate of the reaction increases with the presence of a catalyst.

The rate of the reaction is found to be proportional to the concentration of the reactants. The rate of the reaction is found to be proportional to the temperature. The rate of the reaction is found to be proportional to the presence of a catalyst.

It is found that the rate of the reaction is proportional to the concentration of the reactants. It is found that the rate of the reaction is proportional to the temperature. It is found that the rate of the reaction is proportional to the presence of a catalyst.

vegetative and seed yields gave additional evidence. All analyses were made according to Goulden's Methods of Statistical Analyses.

EXPERIMENTAL RESULTS

Seed Yield Data

The yield of seed from Field A following the first year's application of fertilizer showed considerable variability among plots having the same treatment. It seemed at first glance that no significant differences would be obtained between the various treatments. To determine accurately which treatments gave increases in yield, an analysis of variance was conducted as shown in Table I.

TABLE I

Analysis of variance for seed data for
Field A in 1940

Variance due to	D.F.	Sums of squares	Mean square	F	5%	1%
Blocks	3	1,586.81	528.94	27.34	2.76	4.13
Treatments	8	363.36	45.42	2.35	2.10	2.82
Untreated vs.all others	1	135.24	135.24	6.99	4.00	7.08
Kind of fertilizer	3	133.39	44.46			
Rate of application	1	21.27	21.27			
Kind x Rate	3	73.46	24.49			
Error	60	1,160.90	19.35			
Total	71	3,101.07				

vegetables and seed during the additional period. The
analysis was conducted in the laboratory of the
local health.

ANALYSIS OF SEED

ANALYSIS OF SEED

The field of seed was first a following and
first year's production of fertilized seed was
variability among fields during the same season. It
seemed as if the cause was in the soil conditions
would be obtained between the two of experiments. The
also accounts for the fact that the seed was in
an analysis of various seed samples in 1910.

TABLE 1

Analysis of various seed samples
1910 to 1911

Field No.	Year	Seed Sample	Weight of Seed	Weight of Seed	Weight of Seed
1	1910	1	1.00	1.00	1.00
2	1910	2	1.00	1.00	1.00
3	1910	3	1.00	1.00	1.00
4	1910	4	1.00	1.00	1.00
5	1910	5	1.00	1.00	1.00
6	1910	6	1.00	1.00	1.00
7	1910	7	1.00	1.00	1.00
8	1910	8	1.00	1.00	1.00
9	1910	9	1.00	1.00	1.00
10	1910	10	1.00	1.00	1.00
11	1910	11	1.00	1.00	1.00
12	1910	12	1.00	1.00	1.00
13	1910	13	1.00	1.00	1.00
14	1910	14	1.00	1.00	1.00
15	1910	15	1.00	1.00	1.00
16	1910	16	1.00	1.00	1.00
17	1910	17	1.00	1.00	1.00
18	1910	18	1.00	1.00	1.00
19	1910	19	1.00	1.00	1.00
20	1910	20	1.00	1.00	1.00
21	1910	21	1.00	1.00	1.00
22	1910	22	1.00	1.00	1.00
23	1910	23	1.00	1.00	1.00
24	1910	24	1.00	1.00	1.00
25	1910	25	1.00	1.00	1.00
26	1910	26	1.00	1.00	1.00
27	1910	27	1.00	1.00	1.00
28	1910	28	1.00	1.00	1.00
29	1910	29	1.00	1.00	1.00
30	1910	30	1.00	1.00	1.00
31	1910	31	1.00	1.00	1.00
32	1910	32	1.00	1.00	1.00
33	1910	33	1.00	1.00	1.00
34	1910	34	1.00	1.00	1.00
35	1910	35	1.00	1.00	1.00
36	1910	36	1.00	1.00	1.00
37	1910	37	1.00	1.00	1.00
38	1910	38	1.00	1.00	1.00
39	1910	39	1.00	1.00	1.00
40	1910	40	1.00	1.00	1.00
41	1910	41	1.00	1.00	1.00
42	1910	42	1.00	1.00	1.00
43	1910	43	1.00	1.00	1.00
44	1910	44	1.00	1.00	1.00
45	1910	45	1.00	1.00	1.00
46	1910	46	1.00	1.00	1.00
47	1910	47	1.00	1.00	1.00
48	1910	48	1.00	1.00	1.00
49	1910	49	1.00	1.00	1.00
50	1910	50	1.00	1.00	1.00
51	1910	51	1.00	1.00	1.00
52	1910	52	1.00	1.00	1.00
53	1910	53	1.00	1.00	1.00
54	1910	54	1.00	1.00	1.00
55	1910	55	1.00	1.00	1.00
56	1910	56	1.00	1.00	1.00
57	1910	57	1.00	1.00	1.00
58	1910	58	1.00	1.00	1.00
59	1910	59	1.00	1.00	1.00
60	1910	60	1.00	1.00	1.00
61	1910	61	1.00	1.00	1.00
62	1910	62	1.00	1.00	1.00
63	1910	63	1.00	1.00	1.00
64	1910	64	1.00	1.00	1.00
65	1910	65	1.00	1.00	1.00
66	1910	66	1.00	1.00	1.00
67	1910	67	1.00	1.00	1.00
68	1910	68	1.00	1.00	1.00
69	1910	69	1.00	1.00	1.00
70	1910	70	1.00	1.00	1.00
71	1910	71	1.00	1.00	1.00
72	1910	72	1.00	1.00	1.00
73	1910	73	1.00	1.00	1.00
74	1910	74	1.00	1.00	1.00
75	1910	75	1.00	1.00	1.00
76	1910	76	1.00	1.00	1.00
77	1910	77	1.00	1.00	1.00
78	1910	78	1.00	1.00	1.00
79	1910	79	1.00	1.00	1.00
80	1910	80	1.00	1.00	1.00
81	1910	81	1.00	1.00	1.00
82	1910	82	1.00	1.00	1.00
83	1910	83	1.00	1.00	1.00
84	1910	84	1.00	1.00	1.00
85	1910	85	1.00	1.00	1.00
86	1910	86	1.00	1.00	1.00
87	1910	87	1.00	1.00	1.00
88	1910	88	1.00	1.00	1.00
89	1910	89	1.00	1.00	1.00
90	1910	90	1.00	1.00	1.00
91	1910	91	1.00	1.00	1.00
92	1910	92	1.00	1.00	1.00
93	1910	93	1.00	1.00	1.00
94	1910	94	1.00	1.00	1.00
95	1910	95	1.00	1.00	1.00
96	1910	96	1.00	1.00	1.00
97	1910	97	1.00	1.00	1.00
98	1910	98	1.00	1.00	1.00
99	1910	99	1.00	1.00	1.00
100	1910	100	1.00	1.00	1.00

TABLE II

Mean values in grams for seed yield,
Field A, 1940

Fertilizer	Mean of 4 replicates						Gen. mean
	25 lb. annu- ally	25 lb. bien- nially	Aver- age	75 lb. annu- ally	75 lb. bien- nially	Aver- age	
16-20	4.6	10.2	7.4	9.1	11.9	10.5	8.9
11-48	7.6	3.7	5.6	1.8	7.9	4.9	5.2
2-19	4.8	4.7	4.8	8.7	4.2	6.5	5.6
9-27-9	8.2	4.3	6.3	4.5	9.3	6.9	6.6

Mean yield of 8 check plots = 2.2 grams
A yield of 100 pounds of seed per acre = 24.7
grams per plot.

It is evident from Table I that the sums of squares for treatments in general can be broken down into several component parts, taking out the variance due to check plots, kind of fertilizer applied, rate of application, and the interaction of Kind x Rate. When this is carried out, however, the number of degrees of freedom are so small and the consequent levels of significance so high that individual components have no significant differences. A large number of replications of the experiment would probably have corrected for this and would have shown the expected significance.

There appears to be a very high degree of soil heterogeneity as indicated by a large F value for blocks. This was in agreement with field observations which showed

a much lower apparent seed yield in replicate one, increasing in replicates two and three. The F value for treatments in general is significant beyond the 5% level so that it may be concluded that there are significant differences in yield of seed for the various plot treatments. At the same time the untreated against all treated plots shows a highly significant difference. From this, one may conclude that all treated plots yielded on the average significantly more seed than the untreated check plots.

DISCUSSION

To determine which of the fertilizers gave the largest increases of seed above the checks, the minimum significant difference was calculated according to the formula $\frac{2.2 e}{N}$ where e = standard error and N = number of individual plots in each treatment. A difference of 3.11 grams of seed produced as a result of any two treatments is significant. No significant differences could be found among yields for 11-48, 2-19, or 9-27-9 but the yield for 16-20 was found to be significantly greater than that for either 11-48 or 2-19. In terms of pounds per acre, the minimum significant difference would be $3.11 \times 4.041 = 12.6$ pounds of seed. This would seem to indicate that the 16-20 fertilizer is the better fertilizer for increasing the yield of alfalfa seed under the conditions of this experiment.

The minimum significant differences between individual treatments--that is, fertilizers applied at the two different rates--is $\frac{2\sqrt{2} \times \sqrt{19.35}}{\sqrt{8}} = 4.4$ grams. A comparison

of the means of the individual treatments shows that the 75-pound annual application of 16-20 ammonium phosphate fertilizer gives the largest increase in seed yield. This result is in agreement with Davis and Jones (7) at California who worked with this fertilizer on rice production. Pultz (40) found similar results with sugar beet seed production as did Warner (51), North and Odland (37) and others.

The mean yields of each treatment compared to the mean yield of the checks shows that all treated plots yield higher than the untreated, indicating that fertilizers in general increase seed setting but that no particular rate of application is superior to all other treatments since rate differences are not significant.

An examination of the second year data indicates the same general trend. One might expect from the manner in which the experiment was designed that differences in seed yield due to the time interval between applications would occur.

The minimum allowable difference between light-
visual observations is 10%, and the maximum is 20%.
The difference between the two is 10%.

of the same of the individual observations from the 10-
percent annual observations of the same observations.

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TABLE III

Analysis of variance of seed yield for
Field A, 1941

Variance due to	D.F.	Sums of squares	Mean square	F	5%	1%
Blocks	3	7.60	2.53	.90		
Treatments	16	68.16	4.26	1.51		
Untreated vs.all others	1	10.37	10.37	3.68		
Kind of fertilizer	3	12.67	4.22	1.49		
Rate of application	1	10.00	10.00	3.55		
Time of application	1	16.91	16.91	6.00	4.02	7.17
Kind x Rate	3	15.01	5.01	1.78		
Kind x Time	3	.43	.14	.05		
Rate x Time	1	.20	.20	.07		
Kind x Rate x Time	3	2.57	.86	.30		
Error	52	146.63	2.82			
Total	71	222.39				

TABLE IV

Mean values in grams for seed yield,
Field A, 1941

Fertilizer	Rates per acre						Gen. mean
	25 lb. annu- ally	25 lb. bien- nially	Aver- age	75 lb. annu- ally	75 lb. bien- nially	Aver- age	
16-20	4.6	3.6	4.1	4.7	4.2	4.5	4.3
11-48	2.5	1.8	2.2	4.8	3.0	3.9	3.1
2-19	3.5	2.2	2.8	4.9	4.1	4.5	3.6
9-27-9	4.5	2.9	3.7	3.4	2.9	3.1	3.4

Mean yield of 8 check plots = 2.4 grams
A yield of 100 pounds of seed per acre =
24.7 grams per plot.

An analysis of variance of the data shows that there was a significant increase in yield of the annually treated plots above that of the biennially treated plots. It is apparent that all fertilizers gave slightly increased yields of seed above the check, but no particular fertilizer stands out above the others, since there is no significant difference in evidence between the mean yields for the various treatments. The mean yields at the two rates and the two time intervals, however, show consistently that the annual 75-pound application yielded more seed than the 25-pound annual or biennial application. In most cases the 16-20 fertilizer caused the larger increases in seed production.

An analysis of variance for the two years' data interaction is given in Table V. In this table interactions were not included because none was found to be significant. This indicated that the effect of an individual treatment on seed production did not change from one year to the next because of differences in climatic conditions.

The results of the analysis indicate the same general trend characteristic of the individual analyses. The seed yield is very different for the different blocks, indicating high soil heterogeneity. Differences between the two years in seed production is also very significant from which it may be concluded that the climatic factors had a great influence on seed production in alfalfa. This fact agrees with widespread observations that seed production varies markedly on the same field in different years. No signifi-

cant increases in yield of seed can be attributed to any particular fertilizer treatment above any other treatment. All treatments, however, show a significant increase above the untreated check plots.

TABLE V

Analysis of variance for seed yield of
Field A for 1940 and 1941 combined

Variance due to	D.F.	Sums of squares	Mean square	F	5%	1%
Block	3	779.20	259.73	13.14	2.70	3.97
Years	1	248.56	248.56	12.58	3.94	6.88
Treatments	16	410.66	25.67	1.30	1.78	2.17
Untreated vs.all others	1	110.23	110.23	5.50	3.94	6.88
Kind of fertilizer	3	109.20	36.40			
Rate of application	1	30.23	30.23			
Time of application	1	.25	.25			
Error	108	2133.54	19.76			
Total	143	3571.96				

TABLE VI

Mean values in grams for seed yields,
Field A, 1940 & 1941 combined

Fertilizer	Rate per acre						
	25 lb. annu- ally	25 lb. bien- nially	Aver- age	75 lb. annu- ally	75 lb. bien- nially	Aver- age	Gen. mean
16-20	4.6	6.9	5.7	6.8	8.0	7.4	6.6
11-48	5.0	2.8	3.9	3.3	5.4	4.4	4.1
2-19	4.7	3.5	4.1	6.8	4.1	5.5	4.6
9-27-9	6.4	3.6	5.0	3.9	6.1	5.0	5.0

Mean of 16 untreated check plots = 2.3 grams
A yield of 100 pounds of seed per acre = 24.7
grams per plot.

could be expected in field of work and be attributed to the
 particular fertilizer treatment used in the experiment.
 All treatments, however, show a significant increase above
 the untreated check plots.

TABLE V

Analysis of variance for seed yield of
 Field 2, 1940-41 (continued)

Variance due to					D.F.		Sum of squares		Mean square	
Block	2				2		104.80		52.40	
Yeast	1				1		100.00		100.00	
Treatment	12				12		410.42		34.20	
Untreated to all others	1				1		110.00		110.00	
Kind of fertilizer	3				3		100.00		33.33	
Rate of application	1				1		80.00		80.00	
Time of application	1				1		0		0	
Error	100				100		100.00		1.00	
Total	122				122		1000.00			

TABLE VI

Mean values for seed yield
 Field 2, 1940-41 (continued)

Fertilizer					D.F.		Sum of squares		Mean square	
10-10	1				1		1.0		1.0	
11-11	1				1		1.0		1.0	
12-12	1				1		1.0		1.0	
13-13	1				1		1.0		1.0	

Mean of 10 untreated plots = 1.0 bushels
 Standard deviation = 0.17
 Standard error = 0.17

DISCUSSION

The calculated minimum significant difference between treatments is $\frac{2\sqrt{2} \times \sqrt{19.76}}{\sqrt{8}} = 4.4$ grams. If the means of the individual treatments are compared in Table VI it is found that the 75-pound application of 16-20 gives a significant increase in seed yield above the check or untreated plots, the comparison being between 8.0 grams and 2.3 grams respectively. A similar difference is found between fertilizers in general and the untreated plots. The minimum significant difference is $\frac{2\sqrt{2} \times \sqrt{19.76}}{\sqrt{32}} = 2.2$ grams.

Hence, all fertilizers increase the yield of seed significantly above the untreated plots. It is also apparent that 16-20 ammonium phosphate is the more beneficial although the increase due to its application is not significantly greater than the increase due to the application of the other three fertilizers.

It was stated in a previous discussion that it was unlikely that significant difference would be obtained between the two rates and the two times of fertilizer application. The reason given then applies here but with results from several years' experiments, significance between the two variables would possibly appear in the interaction table. Consistent increases of the annual application over the biennial and of the 75-pound rate above the 25-pound rate in this experiment lead one to expect such a result.

The following table shows the results of the

analysis of the samples taken on 11.11.11. It was

found that the samples taken on 11.11.11 were

very similar to the samples taken on 10.11.11.

The results of the analysis of the samples

taken on 11.11.11 are given in the table

below. The results of the analysis of the

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TABLE VII

Analysis of variance of seed yield,
Field B, 1941

Variance due to	D.F.	Sums of squares	Mean square	F	5%	1%
Blocks	3	2.72	.91	.07		
Treatments	8	115.81	14.48	1.23		
Untreated vs.all others	1	81.30	81.30	6.92	4.00	7.08
Kinds of fertilizer	3	10.49	3.49	.29		
Rate of application	1	22.56	22.56	1.92		
Kind x Rate	3	1.46	.49	.04		
Error	60	705.24	11.75			
Total	71	823.77				

TABLE VIII

Mean values in grams for seed yield,
Field B, 1941

Fertilizer	Rate of application per acre						
	25 lb. annu- ally	25 lb. bien- nially	Aver- age	75 lb. annu- ally	75 lb. bien- nially	Aver- age	Gen. mean
16-20	8.9	5.0	6.9	8.0	7.8	7.9	7.4
11-48	5.7	7.0	6.3	9.6	6.4	8.0	7.2
2-19	5.6	9.1	7.4	6.4	10.8	8.6	8.0
9-27-9	5.0	7.8	6.4	7.5	7.2	7.3	6.9

Mean yield of 8 check plots = 3.9 grams

A yield of 100 pounds of seed per acre = 24.7 grams
per plot.

Data on seed yield as mentioned earlier are available for one year in Field B. An analysis of variance was conducted in a manner similar to that for data from Field A. The yields of seed were very low but more uniform for a

single treatment, indicating greater soil homogeneity. Block differences were not significant and, therefore, the soil was considered to be quite homogeneous over the whole experimental area. The variance due to untreated against all other treatments was highly significant, indicating the same general trends which occurred in Field A, the treated plots yielding significantly higher than the untreated plots. No significant differences were found between treated plots, indicating that all fertilizers affected seed production similarly. No single fertilizer was more beneficial than another. The general trend of the higher rate to give larger seed yields is also maintained when the mean yields of the treatments are compared. The heavier application of fertilizer gives consistently greater seed yields than the lighter application with each fertilizer.

EXPERIMENTAL RESULTS

Vegetative Yield Data

The vegetative yields of all plots were measured in terms of grams per sample of vegetation. These yields may be converted to a pounds-per-acre basis by multiplying by 4.041.

The analysis of variance was calculated using the

green weight of the sample in grams. The results are presented in Table IX.

TABLE IX

Analysis of variance of vegetative weight for
Field A, 1941

Variance due to	D.F.	Sums of squares	Mean square	F	5%	1%
Blocks	3	10,764,328	3,588,109	31.16	2.78	4.18
Treatments	16	10,791,037	674,440	5.86	1.94	2.55
Untreated vs. all others	1	1,056,699	1,056,699	9.18	4.02	7.17
Kind of fertilizer	3	3,518,814	1,172,938	2.90		
Rate of application	1	2,666,280	2,666,280	23.15	4.02	7.17
Time of application	1	1,210,275	1,210,275	2.99		
Kind x Rate	3	99,651	33,217	.08		
Kind x Time	3	1,212,850	404,283	3.51	2.78	4.18
Rate x Time	1	194,151	194,151	1.69		
Kind x Rate x Time	3	823,317	277,439	2.40		
Error	52	5,987,907	115,152			
Total	71	27,543,216				

F values of Blocks, Treatments, and Untreated are based on error. All others are based on Kind x Time interaction, except rate of application.

TABLE X

Mean values in grams of vegetative yields,
Field A, 1941

Fertilizer	Rate per acre						Gen. mean
	25 lb. annu- ally	25 lb. bien- nially	Aver- age	75 lb. annu- ally	75 lb. bien- nially	Aver- age	
16-20	2067	2056	2061	2489	2481	2485	2273
11-48	1586	1397	1491	1832	1803	1818	1654
2-19	1686	1934	1810	2716	1964	2340	2074
9-27-9	2011	1306	1658	2388	1637	2012	1835

Mean yield of 8 check plots = 1574 grams = 3.18 tons per acre.

It is apparent that the various fertilizer treatments had a very pronounced effect upon vegetative growth. Soil heterogeneity is quite evident as indicated by an abnormally large significant F value for blocks. The yields of the blocks differed considerably. The treatments caused very large differences in vegetative growth which are significant beyond the 1% level. When the variance for Treatments is split into components it is found that the plots treated with fertilizer yielded significantly higher than the untreated check plots in vegetative growth. Differences between fertilizers are apparent. The yields for heavier rates of application are significantly higher in vegetative yield than those for the lower rates. The time factor in the application of fertilizers seems to have had little effect upon the vegetative growth.

Analysis of variance was also conducted on Field B data for vegetative weights for 1941. The results are

presented in Tables XI and XII.

TABLE XI

Analysis of Variance of vegetative weight for
Field B, 1941

Variance due to	D.F.	Sums of squares	Mean square	F	5%	1%
Blocks	3	444,501	148,167	2.17	2.76	4.13
Treatments	8	6,618,238	827,280	12.10	2.10	2.82
Untreated vs. all others	1	2,323,592	2,323,592	33.98	4.00	7.08
Kind of fertilizer	3	1,969,353	656,451	9.60	2.76	4.13
Rate of application	1	2,271,803	2,271,803	33.23	4.00	7.08
Kind x Rate	3	53,490	17,830	.26		
Error	60	4,101,844	68,364			
Total	71	11,164,583				

TABLE XII

Mean values in grams of vegetative yields,
Field B, 1941

Fertilizer	Rate per acre						Gen. mean
	25 lb. annu- ally	25 lb. bien- nially	Aver- age	75 lb. annu- ally	75 lb. bien- nially	Aver- age	
16-20	1793	1400	1596	2061	1952	2006	1802
11-48	1159	1224	1192	1589	1373	1481	1336
2-19	1215	1572	1393	1631	1883	1757	1575
9-27-9	1337	1643	1490	1986	1883	1935	1712

Mean yield of 8 check plots = 1035 grams = 2.09
tons per acre.

Presented in Table 12 and 13.

TABLE 12

Analysis of Variance of Experimental Results
Field 3, 1941

Source of Variation	D.F.	Sum of Squares	Mean Square	F	Prob.
Blocks	5	1,041.00	208.20	1.00	.95
Treatments	5	1,041.00	208.20	1.00	.95
Unexplained vs. error	1	1,041.00	1,041.00	5.00	.05
Kind of fertilization	2	1,041.00	520.50	2.50	.10
Rate of application	1	1,041.00	1,041.00	5.00	.05
Kind of rate	1	1,041.00	1,041.00	5.00	.05
Error	60	1,041.00	17.35		
Total	74	1,041.00			

TABLE 13

Mean Values in Pounds of Experimental Results
Field 3, 1941

Source of Variation	D.F.	Sum of Squares	Mean Square	F	Prob.
Blocks	5	1,041.00	208.20	1.00	.95
Treatments	5	1,041.00	208.20	1.00	.95
Unexplained vs. error	1	1,041.00	1,041.00	5.00	.05
Kind of fertilization	2	1,041.00	520.50	2.50	.10
Rate of application	1	1,041.00	1,041.00	5.00	.05
Kind of rate	1	1,041.00	1,041.00	5.00	.05
Error	60	1,041.00	17.35		
Total	74	1,041.00			

Mean value of 8 green lines = 1.00
Mean value of 8 red lines = 1.00

This analysis of the data shows a striking similarity to the results for Field B. The differences in yield in the four replicates are small and not significant, which would lead one to expect strong uniformity in soil composition. The treated plots yielded much more vegetative growth than the untreated plots. Fertilizers differed slightly in their effect on vegetative yield and some gave significantly higher yields than others. The heavier rate of application also gave significant increases in yield over the lighter applications.

Discussion of Vegetative Yield Results from Fields A and B

In order that the most beneficial fertilizer might be ascertained the minimum significant differences were computed for treatments in general, for fertilizers, and for rates, basing the first and last on error and the other one on fertilizer x time interaction. Field A minimum significant differences are 480 grams for treatments, 449 grams for kind of fertilizer, and 170 grams for rate of application. For Field B they are in a similar order 261, 185, and 131 grams, respectively.

A comparison of the mean yields for each fertilizer shows that all fertilizers yield more than the required significant difference above that of the checks in Field B. In

Field A this occurs with respect to 16-20 and 2-19 only. Thus we may assume these to be the most beneficial fertilizers.

The minimum difference values for "between fertilizers" further reduces the data. A comparison of the mean yields of the four fertilizers shows that 16-20 fertilizer yielded more than the required minimum difference above 11-48 in Field A and Field B, but not so with the other fertilizers. This would lead one to believe 16-20 ammonium phosphate to be the most satisfactory for increasing the vegetative growth of alfalfa and 11-48 the least beneficial, although the latter in these experiments gave yields significantly better than those of the untreated plots.

A comparison of the mean yields of the four fertilizers at the 25-pound and 75-pound rates of application shows that in all cases the 75-pound application yielded higher than the lighter application by more than the required minimum significant difference. The heavier rate of fertilizer application, therefore, appears to be more beneficial than the lighter application. Between the fertilizers themselves it is also apparent that the 75-pound application of 16-20 fertilizer gave the largest significant increases in vegetative growth. Thus, we come to the conclusion that 16-20 ammonium phosphate was the most beneficial fertilizer in these experiments.

EXPERIMENTAL RESULTS

Correlation between Seed Yield and Vegetative Growth

An analysis of covariance was computed for both fields for 1941 data between seed yield and vegetative weight. The analysis for Field B is presented in Table XIII and that for Field A in Table XIV. The purpose of this computation was to determine whether vegetative growth was correlated with seed yield and thus, by increasing vegetative growth, whether an increase in seed yield also due to fertilizer applications had occurred.

TABLE XIII

Analysis of covariance between seed yield and vegetative yield for Field B, 1941

Variance due to	D.F.	Sums of squares, hay	Sums of products	Sums of squares, seed	D.F.	bsh	bsh sums of products	Corr. sums of squares, seed	rsh
Replicates	3	444,501	369.9	2.72	2	.00083	.31	2.41	.34*
Treatment	17	7,643,146	32046.2	250.23	16	.00419	134.27	115.96	.73*
Error	51	3,076,936	30151.2	570.82	50	.00980	295.48	275.34	.31*
Treatment + Error	68	10,720,082	62197.4	821.05	67	.00580	360.74	460.31	

	D.F.	Sums of squares	Mean square	F	5%
Treatment + Error	67	460.31			
Error	50	275.34	5.51		
Treat.	17	184.97	10.88	1.97	1.88
Treat.	16	115.96	7.25		
be - bt	1	69.01	69.01	12.55	4.03

* Significant above the 5% level

THE

TABLE XIV

Analysis of covariance between seed yield and vegetative yield for Field A, 1941

Variance due to	D.F.	Sums of squares, hay	Sums of products	Sums of squares, seed	D.F.	bsh	bsh sums of products	Corr. sums of squares, seed	rsh
Replicate	3	10,764,272	241.0	7.60	2	.00002	.01	7.59	.74*
Treatment	17	10,791,037	20093.7	68.16	16	.00186	37.37	30.79	.52*
Error	51	5,987,907	15481.0	146.63	50	.00258	39.94	106.69	
Treatment + Error	68	16,778,944	35574.7	214.79	67	.00212	75.42	139.37	

	D.F.	Sums of squares	Mean square	F	5%
Treatment + Error	67	139.37			
Error	50	106.69	2.13		No values
Treat.	17	32.68	1.92		signifi-
Treat.	16	30.79	1.92		cant
be - bt	1	1.89	1.89		

* Significant above the 5% level

DISCUSSION

In examining Table XIII we see a very significant positive correlation coefficient, r_{sh} , for treatments, meaning that as the yield of vegetation increases, there is an increase in seed production in the plots which had received fertilizer treatment. The regression coefficient, b_{sh} , shows the magnitude of this correlation, namely, with a 1000-gram increase in vegetative yield the seed yield increases by 4.2 grams. The very small seed increase with such a large vegetative increase is probably the result of the yields of seed being very low on all the plots. In a good seed-setting year a much larger seed yield increase would likely be obtained with such a large increase in vegetative growth if the correlation were maintained under such conditions. The repetition of the experiment for several years should give much more evidence on this point. From further examination of this table, particularly the latter section, it is apparent that by using the corrected sums of squares in the analysis table the seed yields when corrected for the increased vegetative growth continue to show a significant difference between different fertilizer treatments. Thus it would be expected that the fertilizers which gave the largest seed increases when the seed yields were analysed by the simple analysis of variance method would continue to give increased yield even when the effects of increased vegetative growth were allowed for.

The mean seed yield for each treatment were then corrected, using the regression coefficient for treatment, basing the correction on the mean yield of vegetation of all the plots in the experiment. The corrected yields were then plotted against the mean vegetative yield for the same treatments. This resulted in an apparent negative correlation when a line was drawn through their mean. The graph showing this effect appears in Figure 1.

The interpretation of such a phenomenon is very important to this experiment. It at once becomes apparent that the largest yielding vegetative plots which previous to correction gave the largest seed yield now give the smallest seed yield. Conversely, the lowest yielding plots now give the highest yield of seed. This indicates that by the application of fertilizers to alfalfa an increase in seed yield is obtained, due to the fertilizers themselves and not to the increase in vegetative growth, as was indicated by the highly significant correlation coefficient. Thus, from the results of these data, it appears that the application of fertilizers has a direct beneficial effect on increasing the seed yield of alfalfa. Before such conclusions could be made definite, however, it is realized that many replications of the experiment showing similar results must be obtained.

Table XIV, which is the covariance analysis for Field A, shows the same general trend. A highly significant

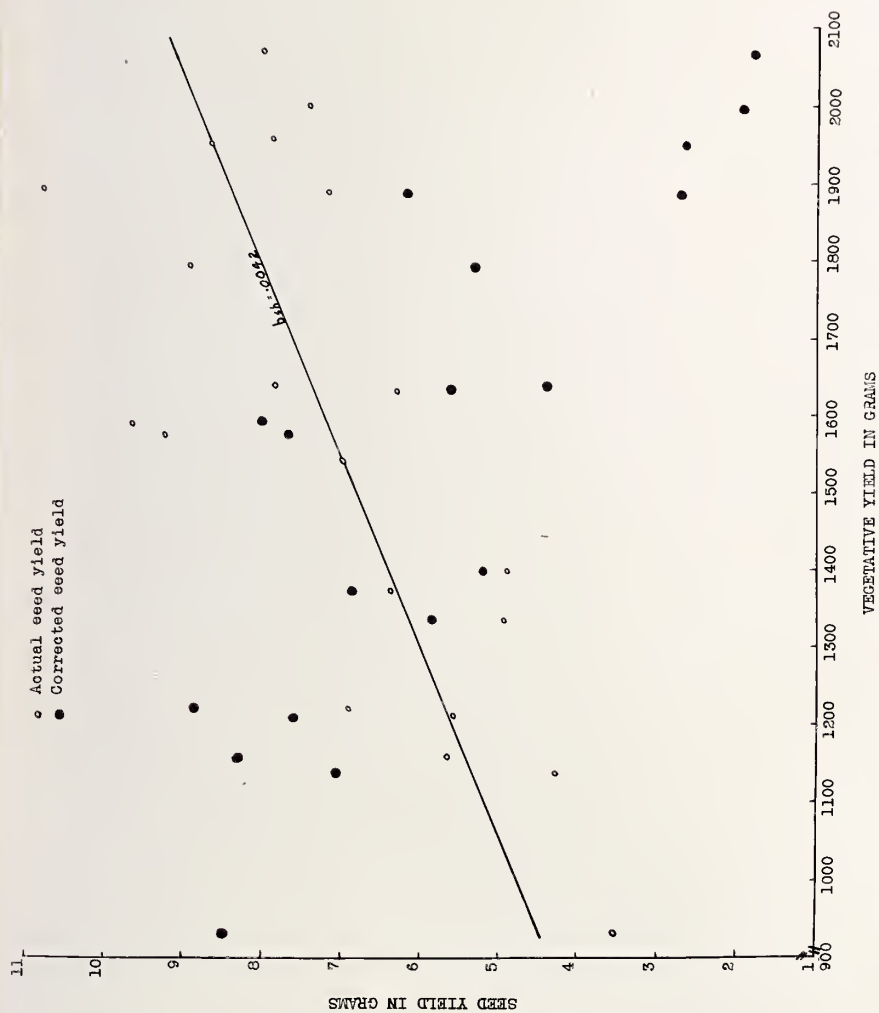


Figure 1

Comparison of actual and corrected seed yields with vegetative yields for each of the 18 treatments Field B, 1941

positive correlation exists between vegetative yield and seed yield. An increase in vegetation is accompanied by an increase in seed yield. Plotting the corrected means for seed yield of differently treated plots gives a similar negative correlation. This is presented in Figure 2. The interpretation is similar to that given for Table XIII. This negative correlation seems to harmonize fairly well with field observations here and elsewhere. Plants which are growing on very rich soil tend to produce excessive vegetative growth and relatively small amounts of seed, whereas other plants growing on similar soil produce smaller amounts of vegetation and large amounts of seed. The same is observed on the poorer class of soils; plants with a luxuriant growth produce little or no seed, while smaller plants produce proportionately much more.

positive correlation between the two variables is indicated by the sign of the correlation coefficient. The correlation coefficient is a measure of the strength and direction of the relationship between two variables. It is calculated by dividing the covariance of the two variables by the product of their standard deviations. The correlation coefficient ranges from -1 to +1. A value of +1 indicates a perfect positive correlation, a value of -1 indicates a perfect negative correlation, and a value of 0 indicates no correlation. The correlation coefficient is a useful tool for analyzing data and understanding the relationships between variables.

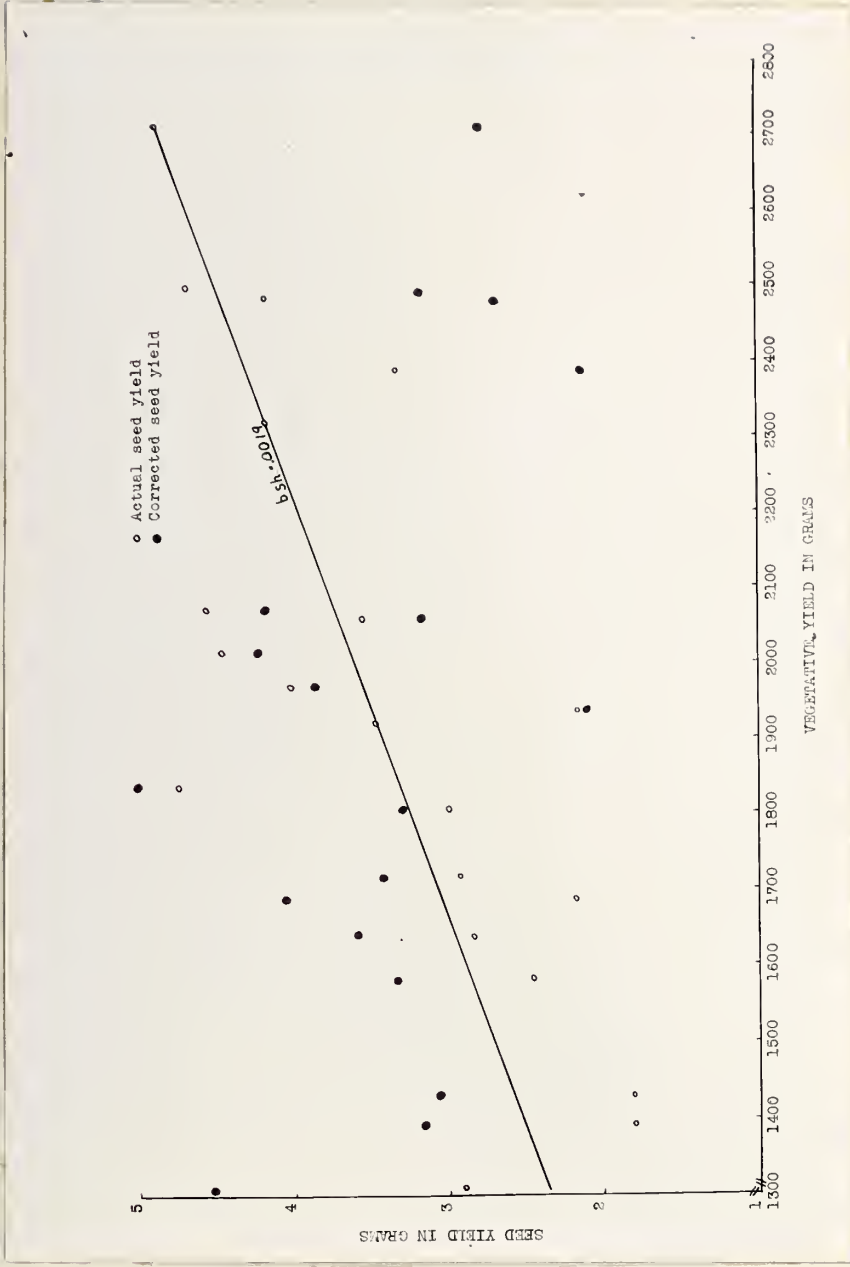


Figure 2

Comparison of actual and corrected seed yields with vegetative yields for each of the 18 treatments Field A, 1941

PART II

GREENHOUSE EXPERIMENTS WITH ALFALFA GROWN IN NUTRIENT WATER CULTURE MEDIA

INTRODUCTION

Earlier in this paper, mention was made of the growing of alfalfa plants under conditions of controlled nutrition. The purpose of this experiment was to determine the effect of individual mineral elements on the seed-producing ability of alfalfa plants. If alfalfa could be grown under such conditions to maturity and seed yields measured, a reliable conclusion could be drawn concerning the effect of mineral elements, which are contained in commercial fertilizers, upon seed production. One might thus be able to determine the effect which a certain fertilizer would have on seed production in field experiments. In undertaking this project many important variables had to be controlled which caused many difficulties in the pursuance of the experiment. Since many of these could not be adequately controlled the conclusions drawn from this experiment cannot be regarded as infallible. The repetition of this test many times would be necessary before justifiable conclusions could be drawn.

THEORY OF THE EARTH
AND ITS HISTORY

CHAPTER I

The first question which presents itself to the mind, when we consider the origin of the earth, is, whether it was created out of nothing, or whether it was created out of some pre-existing matter. The latter opinion is the most reasonable, and is supported by the following arguments.

1. The earth is composed of matter, and matter cannot be created out of nothing. It is evident from the laws of nature, that matter is indestructible, and that it cannot be created or destroyed. It is also evident, that matter is eternal, and that it has existed from all eternity.

2. The earth is composed of matter, and matter cannot be created out of nothing. It is evident from the laws of nature, that matter is indestructible, and that it cannot be created or destroyed. It is also evident, that matter is eternal, and that it has existed from all eternity.

3. The earth is composed of matter, and matter cannot be created out of nothing. It is evident from the laws of nature, that matter is indestructible, and that it cannot be created or destroyed. It is also evident, that matter is eternal, and that it has existed from all eternity.

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7. The earth is composed of matter, and matter cannot be created out of nothing. It is evident from the laws of nature, that matter is indestructible, and that it cannot be created or destroyed. It is also evident, that matter is eternal, and that it has existed from all eternity.

8. The earth is composed of matter, and matter cannot be created out of nothing. It is evident from the laws of nature, that matter is indestructible, and that it cannot be created or destroyed. It is also evident, that matter is eternal, and that it has existed from all eternity.

9. The earth is composed of matter, and matter cannot be created out of nothing. It is evident from the laws of nature, that matter is indestructible, and that it cannot be created or destroyed. It is also evident, that matter is eternal, and that it has existed from all eternity.

10. The earth is composed of matter, and matter cannot be created out of nothing. It is evident from the laws of nature, that matter is indestructible, and that it cannot be created or destroyed. It is also evident, that matter is eternal, and that it has existed from all eternity.

LITERATURE REVIEW

The growing of alfalfa or legumes in water nutrient culture has not been studied to any considerable length. In fact, without exception, no reports could be found in which legume plants were grown in water nutrient culture to maturity. Many references were found which considered the growth of plants to the age of several weeks in water culture but which gave little information of the desired nature. Powers (39) studied the effect of acidity and alkalinity upon the growth of alfalfa in nutrient solution. He used solutions with a pH varying from 5.2 to 7.2, and found that pH 5.6 to pH 6.0 was most suitable for growth. His plants were all grown from seed, and the young seedlings transferred to nutrient solutions. The plants grown at the lowest pH were very unthrifty. Consequently he considered that to be the highest acidity that alfalfa could endure. The experiment was conducted about five weeks and was then discarded. Little information was given concerning the constitution of the solutions or method of aerating the nutrient solutions.

McHargue (33) studied the effect of adding the minor elements B, Mn, Zn, Cu, and I in minute quantities to the culture solution in which oats were growing. He found the greatest grain increases occurred when boron and manganese were added. Eaton (15) found that when boron was absent from nutrient solutions the floral buds abscised from cotton

LITERATURE REVIEW

The growing of alfalfa on leached or sandy soils is a common practice in many areas. Alfalfa has not been studied as thoroughly as other crops, without exception, no reports would be found in which alfalfa plants were grown in water culture. Various references were found which mentioned the growth of alfalfa in the use of several tests in water culture but which gave little information of the detailed nature. (23) studied the effect of acidity and alkalinity upon the growth of alfalfa in distilled solution. He used solutions with a pH ranging from 4.5 to 7.5, and found that at 6.0 to 6.5 was most suitable for growth. His results were all grown from seed, and the young seedlings were transplanted to nutrient solutions. The alfalfa grown in the lowest pH was very unhealthy. Consequently he considered that to be the highest acidity the alfalfa could stand. The solutions was prepared from stock solutions and was distilled. Little information was given concerning the composition of the solutions or means of testing the nutrient solutions. (24) studied the effect of acidity and alkalinity on alfalfa 3, 4, 5, and 6 in the same manner as in the culture solution in which some were growing. He found the greatest yield in neutral solution and some in alkaline and acid. (25) found that alfalfa was grown in distilled solution in the same manner as in the

plants. When ten p.p.m. of boron were added to the nutrient solution, floral abscission was eliminated, and large yields of cotton bolls were obtained.

Hartman and Powers (22) grew wheat plants to maturity in nutrient culture solutions. They found that if less than four p.p.m. of phosphorus were present in the solution little growth took place but, by increasing this to 128 p.p.m. the greatest increase in growth resulted. During early growth, phosphorus was found to increase root elongation and, at a later date, to hasten maturity. Phosphorus at this time was stored in greatest quantities in the seed to be used later by the young developing plant.

Lomanitz (30, 31, 32) studied the effect of sodium chloride in nutrient solutions on the growth of alfalfa. He used Tottingham's solution as the basic solution and added varying amounts of NaCl solution. He concluded that solutions containing NaCl gave higher vegetative yields than the checks. He grew the plants 98 days in solution with considerable success. Utilizing similar methods in a second experiment he found chlorine uptake by alfalfa to correspond directly to the amount of sodium chloride in the solution. The higher concentrations of sodium chloride gave the larger yields of vegetation. The limited evidence reported thus far was used as the basis for the setting up of the following experiment.

MATERIALS AND METHODS

Four plants were selected for growing in nutrient water culture solution. The same plants used in fertility studies by Bolton and Fryer (4, 5) and by Sexsmith (43) were employed in this experiment. Three of these plants, designated 21-23, 47-5, 40-10, were highly fertile, while one, 9-11, was very low in fertility. It was thought that by using clones of these plants, the great variability in seed setting exhibited by those grown from seed of a single plant could be avoided. Thus all the clones of a single plant would have the same genetic constitution and thus the same inherent ability to produce seed. The plants would also be expected to behave under controlled nutrient conditions in a manner similar to that under ordinary field conditions. The same differences in fertility might be expected to occur between clones of two plants in the same nutrient solutions as would occur between clones of the same two plants grown near each other in the field.

Clones of the four plants were obtained by rooting cuttings in moist sand. Healthy, vigorous branches were cut from the selected plants and the cut ends immersed in water with the branches from each plant kept separate. Cuttings were taken from the lower to middle section of the branch only, because it was not known whether there was a

position differential on the branch to produce flowers. Thus, to avoid any differences which might be entailed between basal and tip cuttings, the basal and median portions of the branch were used. The method described by Garcha (18) was followed with slight modifications. The basal cut was made through a node, the upper end being cut about one inch above the second node. All leaves except the single terminal leaflet on the upper node were snipped off. One hundred such cuttings were taken from each of the four plants.

A preliminary trial had been run to test this method and found satisfactory. In the preliminary trial, two types of root-producing stimulators were used. A powder form of Indolebutyric Acid produced only about 30 percent of well-rooted cuttings and so was discarded. A liquid type of root stimulator, "Hormodin A", manufactured by Merck and Co., Rahway, New Jersey, was then used. Three concentrations of this solution were tested, using 100 similar cuttings for each concentration, 5 c.c., 2.5 c.c., and 1.25 c.c. per 250 c.c. of water. Each solution was divided into three parts and placed in 250 c.c. beakers. The 100 cuttings were then placed with their basal ends immersed in the liquid for 24 hours. Excessive evaporation was prevented by covering the tops with paper. The treated cuttings were then placed in moist sand to root. At the end of the three weeks' time counts were made of rooted plants. The strong concentration had killed over 90 percent of the plants, the 2.5 c.c.

concentration about 50 percent, and the weakest solution only 12 percent. Thus the 1.25 c.c. "Hormodin A" per 250 c.c. of water was used in the experiment reported herein. Better results were later obtained by using sterilized sand as the rooting medium in order to prevent the tendency to contract a fungal or bacterial infection which produced rot in later work. It was found impractical to attempt to prevent the inoculation of the roots by legume bacteria. Hence, the cuttings were artificially inoculated with bacteria to give a uniform inoculation.

The nutrient solutions used were those designed by Hoagland and Arnon (24). Five solutions were utilized, one containing all essential elements, a second containing one-half the nitrogen present in the complete solution, a third containing one-half potassium, a fourth one-half phosphorus, and a fifth one-half sulphur. The following table shows the composition per nine litres of each solution. In addition Hoagland's A to Z solution was supplied along with iron tartrate.

TABLE XV

Number of cc. molar solution per
nine-litre crock

	KNO ₃	CaNO ₃	KH ₂ PO ₄	MgSO ₄	Ca(H ₂ PO ₄) ₂ [*]	Mg(NO ₃) ₂
Complete	22.5	22.5	4.5	9.0	--	--
N	22.5	5.6	4.5	9.0	16.9 ^a	--
K	13.5	27.0	--	9.0	2.3 ^b	--
P	24.8	22.5	2.3	9.0	--	--
S	22.5	22.5	4.5	4.5	--	4.5

* Add as M/16

a = 270

b = 36

Each treatment was replicated three times giving a total of sixty crocks, involving five treatments, four plants, and three replicates of each. When the cuttings had rooted sufficiently well, after four weeks, they were transferred to the nutrient solutions. Nine-litre glazed crocks with holes in the bottom plugged with rubber corks were used. The cuttings were inserted in corks, each with a hole bored in the centre and held in place with cotton wool. The corks were then inserted into holes in a tin plate which rested on the top of the crock. Thus the roots of the cuttings were immersed in the nutrient solutions and were protected from the light. The upper portion of the cutting only was visible.

The nutrient solutions were changed every three weeks. Aeration of the solutions every day for 15 minutes was found beneficial and even necessary. An air-compression

013 = 7

11-1

pump supplying a constant air pressure of 15 pounds was used. The air was bubbled through a porous porcelain aerating device attached to a rubber hose which was immersed in the solution. This device gave off uniformly small bubbles of air throughout the solution and did not injure the roots.

When the plants came into flower, each was hand-tripped. The total number of flowers produced and tripped for each crock was recorded. The individual plants in a crock were not kept separate. In the fall, when the plants had ceased flowering and pods ripened, they were counted and picked off. The total number per crock was recorded. When the seed crop had matured and had been picked, the dried tops and roots of the plants were weighed. The total weight of the upper vegetative growth was recorded for each crock separately from the roots.

The data thus secured were analysed by the analysis of variance method to determine the effect of the nutrient solutions on flower, pod, seed, and vegetative production. The results are reported in the next section of this paper.

EXPERIMENTAL RESULTS

group supplying a constant air pressure of 10 pounds per
used. The air was supplied through a pump, connected with
being driven through a 1/2 inch hose with the following
in the solution. This device gave an air pressure of 10
bubbles of air through the solution and all the air
the roots.

When the plants were in the water, each was indi-
cated. The total number of flowers, leaves and roots
for each group was recorded. The individual plants in a
group were not kept separate. In the fall, when the plants
had ceased flowering and lost leaves, they were removed
and picked off. The total number of roots was counted.
When the seed crop had matured and had been dried, the
dried tops and roots of the plants were weighed. The total
weight of the upper vegetative growth was recorded for each
group separately from the roots.

The data have been carefully analyzed by the method
of variance method. To determine the effect of the different
solutions on the root, leaf, and vegetative production.
The results are reported in the next section of this report.

TABLE XVI

Mean yield in grams per crock of alfalfa plants
grown in nutrient solution, 1941

Plant	Solution	No. of flowers tripped	No. of pods set	% pod set	No. of seeds set	No. of seeds per pod	No. of seeds per flower	Mean vegetative yield in grams
21-23	Complete	119	62	52	185	3.0	1.55	13.8
	K	34	17	50	60	3.5	1.76	8.3
	P	10	4	40	14	3.5	1.40	1.5
	S	93	33	33	120	3.6	1.29	10.7
	N	12	-	-	-	-	-	-
47-5	Complete	11	9	82	27	3.0	2.45	18.3
	K	22	9	40.9	21	2.3	0.95	13.2
	P	30	19	52.8	55	2.9	1.53	15.0
	S	20	15	75.0	47	3.1	2.35	17.9
	N	10	-	-	-	-	-	-
40-10	Complete	191	43	22.5	73	1.7	.38	16.8
	K	73	12	16.4	35	2.9	.48	19.2
	P	46	7	15.2	15	2.1	.33	12.0
	S	165	40	24.2	93	2.3	.57	13.2
	N	36	-	-	-	-	-	-
Mean of all three plants	Complete	107	38	35.5	95	2.5	.89	20.5*
	K	43	13	30.2	39	3.0	.91	15.4
	P	31	10	32.2	28	2.8	.90	12.2
	S	93	30	32.3	86	2.9	.93	20.0
	N	19	-	-	-	-	-	-

* Plant 9-11 included, so four-plant average

IX. 19. 7

actual exhibits to support the claim, and
that, notwithstanding the fact that the

An examination of Table XVI shows the consistent inferiority of low phosphorus and low potassium nutrition on alfalfa yields in comparison with the complete nutrient solution. In all cases there is a lowering of the mean vegetative yield, due to reduced P and K nutrition. In the case of the number of flowers produced and tripped, a similar relationship holds. This varies slightly between different plants for which no apparent reason can be given. Pod setting and seed production followed the same general trend; a decrease in yield due to the low level of P and K nutrition was exhibited. Plant 9-11 did not produce sufficient flowers or set any seed and thus was not included in the analyses.

DISCUSSION

TABLE XVII

Analysis of variance for number of
flowers tripped

Variance due to	D.F.	Sums of squares	Mean square	F	5%	1%
Treatments	4	54,396	13,599	4.84	2.69	4.02
Plants	2	51,542	25,771	9.17	3.32	5.39
Treatments x Plants	8	36,799	4,599	1.64	2.27	
Error	30	84,267	2,809			
Total	45	227,004				

Table XVII shows that the different nutrient solutions caused a difference in the number of flowers produced and tripped. The minimum significant difference for between treatments shows the $\frac{1}{2}$ P and $\frac{1}{2}$ K solutions to be significantly lower in number of flowers produced than the complete nutrition and the $\frac{1}{2}$ S solution. Thus a deficiency of both phosphorus and potassium decreases the flower production of alfalfa plants in this experiment. It is also evident that plant differences are highly significant, plant 40-10 yielding more than the required minimum to be significantly better than plant 47-5 or plant 9-11. Plant 9-11, a yellow-flowered falcata type plant, produced very few flowers in one or two solutions and none in the others. The vegetative growth was satisfactory in the nutrient solutions, but flower formation was adversely affected.

Plant fertility, as measured by pod setting and seed production, shows considerable difference due to nutrition. Table XVIII presents the analysis of variance for pod setting.

TABLE XVIII

Analysis of variance for pod setting in
nutrient solution

Variance due to	D.F.	Sums of squares	Mean square	F	5%	1%
Treatments	3	4,850	1,617	4.37	3.01	4.72
Plants	2	1,647	824	2.23	3.40	
Treatments x Plants	6	4,043	672	1.82	2.51	
Error	24	8,881	370			
Total	35	19,421				

These results show that the treatment with 100 g/m² of
along caused a difference in the growth of the plants
and reduced the relative efficiency of the treatment.
treatment along the 20 g/m² and a reduction in the efficiency
lower in number of flowers per plant than the control.
tion and was 1/2 control. This is explained by the fact
growth and relative efficiency of the treatment with 100 g/m²
efficiency plants in this experiment. It is a fact that
plant differences were clearly observed. These differences
lay more than the treatment effect in the experiment.
between other than 100 g/m² or other 20 g/m². These differences
flowers plants that were treated with 100 g/m² in
one of two conditions and was in the control. The reduction
growth was satisfactory in the treatment with 100 g/m² and
formation was adversely affected.

These results, in connection with the growth of
seed production, show that the treatment with 100 g/m² of
tion. These results show the effect of treatment with 100 g/m²
seed.

TABLE II

Analysis of variance for the effect of
treatment on seed production

Variation due to		D.F.		Mean square		F		P	
Treatment		1		1,000		1,000		1,000	
Error		1		1,000		1,000		1,000	
Treatment x Error		1		1,000		1,000		1,000	
Total		2		2,000		2,000		2,000	
Grand Total		2		2,000		2,000		2,000	

It is evident from the table that nutrition influences pod setting of alfalfa in this experiment. The calculated minimum significant difference between treatments is 18.0 pods. The complete solution and $\frac{1}{2}$ sulphur solution thus were both significantly better than $\frac{1}{2}$ phosphorus and $\frac{1}{2}$ potassium solutions. Again evidence presented shows the great effect of lower P and K nutrition on lowering fertility of alfalfa.

The data on seed production indicate the same general trend but the analysis of variance shows less significance in this experiment.

TABLE XIX

Analysis of variance for seed production in
nutrient solution

Variance due to	D.F.	Sums of squares	Mean square	F	5%
Treatments	3	30,304	10,101	2.68	3.01
Plants	2	21,006	10,503	2.79	3.40
Treatments x Plants	6	32,698	5,449	1.45	2.51
Error	24	90,390	3,766		
Total	35	174,398			

There is no significant difference between yields of seed for the four solutions, but there seems to be strong indication that the low phosphorus and low potassium solutions produced a considerably lower seed set than the complete

solution. The calculated minimum significant difference is 50 seeds between treatment mean values. Table XVI shows the complete solution yielded more than the required minimum above $\frac{1}{8}$ P and $\frac{1}{8}$ K solutions. The inference which may be drawn is that the elements phosphorus and potassium may exert a greater influence upon seed production than sulphur, as indicated by this preliminary experiment.

The importance of phosphorus and potassium in alfalfa production was further emphasized by an analysis of variance on vegetative yields.

TABLE XX

Analysis of variance of vegetative yields of
alfalfa in nutrient solution

Variance due to	D.F.	Sums of squares	Mean square	F	5%	1%
Treatments	3	320.34	106.78	5.83	3.30	5.34
Plants	3	611.47	203.82	11.13	3.30	5.34
Treatments x plants	9	341.80	37.98	2.07	2.21	
Error	32	586.15	18.32			
Total	47	1859.76				

The vegetative yields of the plants in the four nutrient solutions are significantly different. The minimum significant difference is 3.5 grams, which shows from reference to Table XVI mean values of all plants that the low phosphorus and low potassium solutions produce significantly less

collected. The collected material was dried in a oven at 60°C for 72 hours. The dried material was then ground to a fine powder and passed through a 60 mesh sieve. The material was then stored in airtight containers until used. The material was then used in the experiment. The results of the experiment are shown in Table I. The results show that the material collected from the field was significantly different from the material collected from the laboratory. The results also show that the material collected from the field was significantly different from the material collected from the laboratory. The results also show that the material collected from the field was significantly different from the material collected from the laboratory.

TABLE I

Analysis of variance of vegetative yield of alfalfa in different treatments

Variance due to		D.F.		Mean square		F		P	
Treatments		8		10.75		10.75		0.01	
Plants		2		11.25		11.25		0.01	
Treatments x plants		16		1.25		1.25		0.01	
Error		20		0.25		0.25		0.01	
Total		46		13.50		13.50		0.01	

The vegetative yield of the plants in the field

nutrient solutions are significantly different. The results show that the material collected from the field was significantly different from the material collected from the laboratory. The results also show that the material collected from the field was significantly different from the material collected from the laboratory. The results also show that the material collected from the field was significantly different from the material collected from the laboratory.

vegetation than the complete or half sulphur solutions. Differences in yield between the four plants were also evident, plants 47-5 and 40-10 giving the highest yield. All plants reacted similarly in the different solutions as indicated by treatment by plant interaction. The results of all the analyses on flower, seed, pod, and vegetative production seem to indicate the necessity of adequate phosphorus and potassium in the nutrition of alfalfa in this experiment.

GENERAL DISCUSSION

The results of these investigations indicate the necessity of continuing the experiments for a number of years, to obtain greater significance between different fertilizer treatments. A general trend for increased seed production, due to application of fertilizer, is apparent but, with the limited amount of data available, little significance can be attached to the results. There are some small differences between the kinds of fertilizers applied in the experiments, which seem to indicate the superiority of 16-20 ammonium phosphate. One would not expect the application of nitrogen to the soil to have a beneficial effect on a leguminous crop, since the nitrogen-fixing bacteria are present in abundance and should supply adequate amounts of this nutrient. This would suggest that phosphorus was the prime factor for increasing the seed yield. Such being the case, one might expect most benefit from the

highest phosphate fertilizer, viz., 11-48. This is quite contrary to the results obtained in this experiment, although all fertilizers did increase the seed yield above that of the untreated check plots.

One might expect the heavier rates of application of fertilizer to cause the larger increases in yields of seed and forage. Indications from these experiments seem to support this expectation. In no case would heavier rates be expected to be detrimental. Several workers have found excessively heavy applications to be detrimental but these applications were all in the range of 500 to 1000 pounds per acre. Both fields in 1941 indicated yield increases in seed and vegetation from the heavier rates of application.

The frequency of application factor in Field A, 1941, indicated that the annual application of fertilizers gave the greatest benefit to seed yield. At the low rates of application the residual effect of the fertilizers would be relatively small since a very large percentage of the plant nutrients in the fertilizer are water soluble and immediately available to the plants. Few workers have found the residual effect to carry over to succeeding years, and then only when very heavy rates of application were used.

Fertilizer 11-48, on analysis, discloses a very low percentage of sulphur, while fertilizers 16-20 and 2-19 are found to contain relatively much higher proportions of sulphur. The presence of this element may thus have some

benefit when applied with a high phosphorus fertilizer. Wyatt et al (54) found substantial increases from 16-20 ammonium phosphate and, with the further application of sulphur, even greater benefit to legumes on the gray wooded soils of Alberta.

The highly significant positive correlation between seed yield and vegetative yield for both fields in 1941 showed that fertilizers apparently increased seed setting as well as the vegetative growth of the plant under the conditions of the experiment. An examination of the mean yields for the various fertilizer treatments showed that the larger the seed yield the larger was the vegetative growth. This result is contrary to that of Evans (16) who found that fertilizer applications increased the seed yield of timothy but had very little effect on vegetative growth. He concluded that fertilizers directly increased the seed yield of timothy. Other workers, North and Odland (37), Pultz (40), and Schuster (42), have found similar results with Colonial Bent grass, sugar beets, and soybeans, respectively. The application of fertilizers increased the yield of both seed and vegetation, the greatest effect being on yield of seed.

In view of the results obtained in the nutrient water culture experiment, one may draw some suggestive conclusions relating to the effect of certain elements on seed production in alfalfa. There appears to be a greater necessity of phosphorus and potassium over that of sulphur for

flower and seed formation. The reduction of phosphorus lowered significantly the numbers of flowers and seeds produced compared to those caused by the reduction of the sulphur content of nutrient solution. At the same time it is evident under the conditions of the fertilizer experiment reported here that the fertilizers containing the largest amounts of sulphur gave the greatest increases in seed yield, while the highest phosphate fertilizer, 11-48, gave the lowest yield. This may be accounted for by the chemical analysis of an average gray soil which shows the upper soil layers to be very low in sulphur and fairly low in phosphorus. The sulphur is leached to a very low level in the soil horizon. This would then be a more limiting element in the gray soils than phosphorus. It might be expected that high sulphur fertilizers would give greater increases in yield of seed and forage than high phosphate and low sulphur fertilizers. This would lead one to believe that with adequate sulphur present in the soil the addition of phosphate fertilizers would increase the yield of seed and forage as indicated by these experiments on the gray soils of Alberta.

The results of the experiment which have been obtained thus far do not furnish sufficient evidence to account definitely for any particular effect of mineral element on the reproductive processes of alfalfa. Further investigation of this problem may give more adequate information to account for these effects.

SUMMARY

1. The application of the commercial fertilizers, ammonium phosphate 16-20, and 11-48, single superphosphate 2-19, and the complete fertilizer 9-27-9, which were investigated in these experiments, were found to increase the seed yield of alfalfa significantly above that of the untreated check plots.
2. Ammonium phosphate 16-20 was found to give the largest increases in both seed and vegetative yields when applied at the rate of 75 pounds per acre.
3. The 75-pound rate of fertilizer application, annually produced larger seed and vegetative yields than the 25-pound rate applied biennially or annually under the conditions of these experiments.
4. Seed yield was found to be positively correlated with vegetative growth, the plots having the heaviest vegetative growth producing the largest seed yield.
5. Fertilizer applications appeared to increase the seed yield of alfalfa directly and not indirectly through the increase in vegetative growth.
6. The experiments conducted with alfalfa cuttings showed that these could be grown to produce mature seed in nutrient water culture solutions.

7. Low levels of phosphorus and potassium in the nutrient solution were found to decrease the numbers of flowers produced, number of pods set, and the number of mature seeds formed, below the numbers obtained from the complete nutrient solution and the low sulphur solution.

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REFERENCES

1. ASO, K. On the practical application of manganous chloride on rice culture. Bul. Col. Agr. Tokyo Imp. Univ. 6:131. 1904.
2. AVDONIN, N.S. Certain aspects in the nutrition of millet. Soc. Zern. Hoz. No. 4:127-146. 1936; Herbage Abs. 10(2) June, 1940.
3. BOBKO, E.V. and MATVEEVA, T.V. The absorption of boron by soils. Ann. Agron. 6:691-701. 1936.
4. BOLTON, J.L. A study of the causes of sterility in Medicago sativa L. (alfalfa) in relation to seed setting. Univ. of Alta. M.Sc. Thesis, April, 1936.
5. BOLTON, J.L. and FRYER, J.R. Interplant variations in certain seed setting processes in alfalfa. Sci. Agr. 18:148-160. 1937.
6. BOSWELL, V.R. and JODIDI, S.L. Chemical composition and yield of Alaskan peas as influenced by certain fertilizers and by stage of development. Jour. Agr. Res. 48:703-736. 1934.
7. DAVIS, L.L. and JONES, J.W. Fertilizer experiments with rice in California. U.S.D.A. Tech. Bul. 718:1-21. 1940.
8. DEMKINA, A. Increasing flax yields by stimulation. Abstract from Biography of Minor Elements by L.G. Willis, Chilean Nitrate Educational Bureau Inc. p. 618. 1939.
9. DIJAKOVA, E.V. The effect of boric fertilizers on development and seed yield of lucerne. Dokl. Akad. Sc. No. 22:12-17. 1938. Herbage Abs. 9:296. 1939.
10. _____ The significance of phosphoric nutrition in increasing seed yield of lucerne in the first year of growth. Selek. Semenovod. 6(22-4). 1940. U.S.S.R. Inst. of Fodders Lugovaja Moscow Region. Herbage Abs. 11:170. 1941.
11. DMITRIEV, K.A. Use of boron fertilizer in the cultivation of red clover. Chemisation Socialistic Agr. 8(5): 20-25. 1933. C.A. 34:4209.

REFERENCES

1. ASO, A. On the question of the origin of the...
1951. 11:100. 1951.
2. ASO, A. On the question of the origin of the...
1951. 11:100. 1951.
3. ASO, A. On the question of the origin of the...
1951. 11:100. 1951.
4. ASO, A. On the question of the origin of the...
1951. 11:100. 1951.
5. ASO, A. On the question of the origin of the...
1951. 11:100. 1951.
6. ASO, A. On the question of the origin of the...
1951. 11:100. 1951.
7. ASO, A. On the question of the origin of the...
1951. 11:100. 1951.
8. ASO, A. On the question of the origin of the...
1951. 11:100. 1951.
9. ASO, A. On the question of the origin of the...
1951. 11:100. 1951.
10. ASO, A. On the question of the origin of the...
1951. 11:100. 1951.
11. ASO, A. On the question of the origin of the...
1951. 11:100. 1951.

12. DMITRIEV, K.A. The effect of microelements on limed podsol soils on the development of the crop of red clover. *Pedology U.S.S.R.* 4:114-133. 1939. (C.A. 34:7054).
13. _____ Effect of molybdenum on red clover crops
Chemisation Socialistic Agr. 7(8):80-81. 1938. (C.A. 34:2996).
14. EATON, F.M. Interrelations in the effects of boron and indoleacetic acid on plant growth. *Bot. Gaz.* 101: 700. 1940.
15. _____ Boron requirements of cotton. *Soil Sci.* 34:301-305. 1932.
16. EVANS, M.W. Effects of application of nitrate of soda upon the yields of timothy hay and seed. *Jour. Amer. Soc. Agron.* 26:235-240. 1934.
17. FELLERS, C.F. The effect of fertilizer treatment and certain minerals on the yield. *Soil Sci.* 6:81-129. 1918.
18. GARCHA, H.S. The use of phytohormones in facilitating the clonal propagation of alfalfa, wheat, and oats. M.Sc. Thesis. Univ. of Alta. Coll of Agr. April, 1938.
19. GLYNNE, M.D. A note on some experiments dealing with sulphur treatment of a soil and its effect on wheat yield. *Roy. Soc. Victoria Proc. n.s.* 42:30-35. 1929.
20. GOULDEN, C.H. *Methods of Statistical Analyses.* 1937. Revised edition. Burgess Publishing Company, Minneapolis, Minn.
21. GREEN, J. Report on phosphate investigations, 1934. *Mont. Agr. Expt. Sta. Bul.* 296. Jan., 1935.
22. HARTMAN, C. and POWERS, W.L. The crop producing power of limited quantities of essential plant nutrients. *Soil Sci.* 25:371-378. 1925.
23. HILTNER, L. and KORFF, G. Action of various fertilizers especially manganese sulphate on the growth of oats. *Jour. Soc. Chem. Ind.* 37:159. 1918.
24. HOAGLAND, D.R. and ARNON, D.I. The water culture method of growing plants without soil. *Univ. of California Coll. of Agr. Berkley Ag. Exp. Sta. Cir.* 347. 1938.
25. HUGHES, J. The action of lime on soil. *Jour. Bath and West and South Counties Soc.*, 5 ser. (13(1918-19): 34-35). 13:34-35. 1918.

12. TWITNEY, L.E. The effect of temperature on the rate of growth of the green alga, *Chlorella vulgaris*. *Journal of Experimental Botany*, 1950, 1: 1-10.
13. TWITNEY, L.E. The effect of temperature on the rate of growth of the green alga, *Chlorella vulgaris*. *Journal of Experimental Botany*, 1950, 1: 1-10.
14. WATSON, W.M. Investigations on the effect of light on the growth of the green alga, *Chlorella vulgaris*. *Journal of Experimental Botany*, 1950, 1: 1-10.
15. WATSON, W.M. Investigations on the effect of light on the growth of the green alga, *Chlorella vulgaris*. *Journal of Experimental Botany*, 1950, 1: 1-10.
16. WATSON, W.M. Investigations on the effect of light on the growth of the green alga, *Chlorella vulgaris*. *Journal of Experimental Botany*, 1950, 1: 1-10.
17. WATSON, W.M. Investigations on the effect of light on the growth of the green alga, *Chlorella vulgaris*. *Journal of Experimental Botany*, 1950, 1: 1-10.
18. WATSON, W.M. Investigations on the effect of light on the growth of the green alga, *Chlorella vulgaris*. *Journal of Experimental Botany*, 1950, 1: 1-10.
19. WATSON, W.M. Investigations on the effect of light on the growth of the green alga, *Chlorella vulgaris*. *Journal of Experimental Botany*, 1950, 1: 1-10.
20. WATSON, W.M. Investigations on the effect of light on the growth of the green alga, *Chlorella vulgaris*. *Journal of Experimental Botany*, 1950, 1: 1-10.
21. WATSON, W.M. Investigations on the effect of light on the growth of the green alga, *Chlorella vulgaris*. *Journal of Experimental Botany*, 1950, 1: 1-10.
22. WATSON, W.M. Investigations on the effect of light on the growth of the green alga, *Chlorella vulgaris*. *Journal of Experimental Botany*, 1950, 1: 1-10.
23. WATSON, W.M. Investigations on the effect of light on the growth of the green alga, *Chlorella vulgaris*. *Journal of Experimental Botany*, 1950, 1: 1-10.
24. WATSON, W.M. Investigations on the effect of light on the growth of the green alga, *Chlorella vulgaris*. *Journal of Experimental Botany*, 1950, 1: 1-10.
25. WATSON, W.M. Investigations on the effect of light on the growth of the green alga, *Chlorella vulgaris*. *Journal of Experimental Botany*, 1950, 1: 1-10.

26. HUNTER, H. and HARTLEY, H.D. Relation of ear survival to the nitrogen control of certain varieties of barley. Jour. Agr. Sci. 28:472-502. 1938.
27. KALUZHASKII, V. Sulphur as a complementary fertilizer. Ann. Inst. Agron. Saratov 1(1):99-104. 1923.
28. KONOVALOV, N.I. The question of the different correlations between lime and magnesia in the nutritive solutions. Russ. Jour. Expt. Landw. 8(3):257-280. 1907.
29. KUROCKIN, P.N. Fertilization of soil as a method of increasing yield of red clover. Herbage Abs. 9:235. 1939.
30. LOMANITZ, S. A preliminary study of the effects of sodium chloride upon alfalfa grown in solution cultures. Soil Sci. 16:183-195. 1923.
31. _____ The influence of sodium chloride upon alfalfa grown in solution cultures. Soil Sci. 18:353-371. 1924.
32. _____ A study of physiological balance for alfalfa in solution cultures. Soil Sci. 22:97-109. 1925.
33. McHARGUE, J.S. Evidence that manganese, copper, zinc, and boron are necessary factors in the art of agriculture. Abstract in the American Fertilizer. 71(7):17. 1929.
34. _____ The role of manganese in plants. Jour. Amer. Chem. Soc. 44:1592. 1922.
35. McMURTY, J.E., Jr. Distinctive plant symptoms caused by deficiency of any one of the chemical elements essential for normal development. Bot. Rev. 4:183-204. 1938.
36. MILES, S.R. Use of small amounts of nitrogen for corn in addition to phosphorus and potassium. Jour. Amer. Soc. Agr. 26:129-137. 1934.
37. NORTH, H.F.A. and ODLAND, T.E. Seed yields of Rhode Island Colonial Bent (Agrostis tenuis) as influenced by the kind of fertilizer applied. Jour. Amer. Soc. Agr. 26:939-945. 1934.
38. PILAND, J.R. and IRELAND, C.F. Application of borax produces seed set in alfalfa. Jour. Amer. Soc. Agr. 33: 938-939. 1941.
39. POWERS, W.W. The effect of hydrogen-ion concentration on the growth of certain plants. Soil Sci. 24:1-9. 1927.

40. PULTZ, W.M. Relation of nitrogen to yield of sugar beet seed and to accompanying changes in the composition of roots. Jour. Agr. Res. 54(9), May 1, 1937.
41. REYNOLDS, E.B. and REA, H.E. Effect of rate and time of application of nitrate of soda. Tex. Agr. Expt. Sta. Bul. 490:1-20. 1934.
42. SCHUSTER, G.L. Influence of fertilizers on yield and maturity of soybeans. Jour. Amer. Soc. Agron. 14: 193-197. 1922.
43. SEXSMITH, J.J.P. Studies relating to fertility in alfalfa (Medicago sativa L.). M.Sc. Thesis unpublished. Univ. of Alta. Coll. of Agr. April, 1940.
44. SHKOLNICK, M. The need of plants for boron. Compt. Rend. Acad. Sci. U.S.S.R. 2:167-170. 1935.
45. SNEDECOR, G.W. Statistical Methods Applied to Experiments in Agriculture and Biology. Collegiate Press Inc. Ames, Iowa. 1937.
46. TOEVS, J.L. and BAKER, O.G. Progress report of phosphate and other fertilizer investigations at Aberdeen Branch Experimental Station. Idaho Agr. Expt. Sta. Bul. 230:3-27. 1939.
47. TOKUOKO, M. and HITOSHI, M. Effects of boron on the growth of the rice plant. Jour. Soc. Trop. Agr. 8:211-220. 1936.
48. TOLMAN, B. and STOKER, G.L. Sulphur and nitrogen deficiency relationships in sugar beets grown for seed in Oregon. Jour. Amer. Soc. Agron. 33:1072-9. 1941.
49. TRUOG, E. and HAMBURG, N. Available calcium and magnesium in relation to phosphate utilization. Jour. Amer. Soc. Agron. 23:1055. 1931.
50. USOV, V.A. On cultivation of narrow leaved lupins for grain in Vologda Province. Trudy Vologod Seljiskhoz. 1:134-138. 1940. Herbage Abs. 11(5). 1941.
51. WARNER, J.D. Fertilizers and gruiting of cotton. Jour. Amer. Soc. Agron. 18:1044-1050. 1926.
52. WATSON, D.J. The effect of applying a nitrogenous fertilizer to wheat at different stages of growth. Jour. Agr. Sci. 26:391-414. 1936.

- 40. JONES, J. E. The effect of the rate of growth of the plant on the rate of growth of the root. *Ann. Bot.* 1937.
- 41. JONES, J. E. and J. E. JONES. The effect of the rate of growth of the plant on the rate of growth of the root. *Ann. Bot.* 1937.
- 42. JONES, J. E. and J. E. JONES. The effect of the rate of growth of the plant on the rate of growth of the root. *Ann. Bot.* 1937.
- 43. JONES, J. E. and J. E. JONES. The effect of the rate of growth of the plant on the rate of growth of the root. *Ann. Bot.* 1937.
- 44. JONES, J. E. and J. E. JONES. The effect of the rate of growth of the plant on the rate of growth of the root. *Ann. Bot.* 1937.
- 45. JONES, J. E. and J. E. JONES. The effect of the rate of growth of the plant on the rate of growth of the root. *Ann. Bot.* 1937.
- 46. JONES, J. E. and J. E. JONES. The effect of the rate of growth of the plant on the rate of growth of the root. *Ann. Bot.* 1937.
- 47. JONES, J. E. and J. E. JONES. The effect of the rate of growth of the plant on the rate of growth of the root. *Ann. Bot.* 1937.
- 48. JONES, J. E. and J. E. JONES. The effect of the rate of growth of the plant on the rate of growth of the root. *Ann. Bot.* 1937.
- 49. JONES, J. E. and J. E. JONES. The effect of the rate of growth of the plant on the rate of growth of the root. *Ann. Bot.* 1937.
- 50. JONES, J. E. and J. E. JONES. The effect of the rate of growth of the plant on the rate of growth of the root. *Ann. Bot.* 1937.

53. WITHROW, R.B. Nutrient solution methods of crop production. Dep't Hort., Purdue Univ.
54. WYATT, F.A., NEWTON, J.D., IGNATIEFF, V. Wooded soils and their management. Bul. 21, 3rd edition, Univ. of Alta. Coll. Agr. 1941.

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